



## FLIGHT SYSTEMS & SERVICING PROGRAM ENGINEERING MEMORANDUM

<b>TITLE</b>  <b>HST Mechanism Design Requirements and Guidelines</b>			<b>EM: FS&amp;S 1483</b> <b>DATE: 7 March 2001</b>  <b>REVISED:</b>
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### 1 INTRODUCTION

Spacecraft electro-mechanical devices and mechanisms require special attention during the design, development, test and integration phases of any program. Due to their complexity, it is often difficult to model and analyze performance characteristics such as structural stiffness and life. Therefore, verification often requires a combination of analysis and test. In order to achieve mission success, specific characteristics and complexities must be considered throughout all phases of the mechanism development. This Engineering Memorandum (EM) defines the HST program requirements for all new and modified electro-mechanical devices and mechanisms including, but not limited to, Space Support Equipment (SSE), Orbital Replacement Units (ORU), and Scientific Instruments (SI). This EM does not cover mechanism requirements for Safety Critical Items (see Ref. (c)).



## **2 MECHANISM REQUIREMENTS**

The following should be incorporated into the design, manufacturing & test process of spacecraft mechanisms in order to achieve the highest rate of success for mechanism performance throughout the life of the program:

### **2.1 STRUCTURE ANALYSIS**

Each mechanism should be analyzed for worst case stresses in the stowed for launch and landing, and on-orbit configurations (including thermal environment, gradients, etc.). A fracture analysis should be performed where applicable per NSTS 1700.7B. These analyses must show positive margins of safety using the appropriate project factors of safety. Material strength and other mechanical and physical properties shall be selected from MIL-HDBK-5. Each mechanism should be random vibration tested at either the component or system level.

### **2.2 HARDWARE**

Snap rings should not be used to retain pins in linkages or other applications where a moment load may be applied to the snap ring. Mechanical stops or shoulders should be designed to a structural yield factor of safety, based on static analysis, of at least 2.0 for the maximum impact load. If it can be shown that the dynamic analysis inherently accounts for dynamic load amplification as a result of the impact, program factors of safety may be used. The use of locking features on all hardware is recommended.

### **2.3 PRELOAD**

Mechanism preload should be determined to prevent gapping by using worst-case loads (launch, landing, or on-orbit) x 1.25 gapping Factor of Safety (FS) x 1.20 instrumentation FS (based on the accuracy of the measurement device, i.e. belleville washer, calibrated torque, etc.). Deviations from this equation should be considered on a case by case basis only, i.e. where EVA capability limits the load.

### **2.4 STIFFNESS**

A stiffness analysis or test should be performed and results compared to the system model. Deviations from predicted values should be explained and test data correlated.

## **2.5 THERMAL ANALYSIS & TEST**

A thermal environment should be specified for each mechanism. All analyses should consider the worst case environment. Thermal finishes and degradation over life should be considered. Mechanisms should be thermal (vacuum if necessary) cycled with functional tests conducted at the worst case hot and cold temperature plateaus. Parasitic forces and torques should be measured at these extremes.

## **2.6 HINGES & BEARINGS**

Self-aligning features, such as self-aligning bearings and rod-ends, should be used where practicable to preclude binding of pivoting elements. Use of continuous hinges such as piano hinges should be avoided.

For all mechanisms that include ball bearings, the bearing shall be designed such that the max mean hertzian contact stress does not exceed 335,000 psi under worst case, static loading conditions including bulk temperature and gradient effects. Operating stresses shall not exceed 120,000 psi. Bearing fatigue life calculations shall be based on survival probability of 99.95%

## **2.7 LUBRICANT ANALYSES**

All mechanisms that require lubrication to meet life requirements should have a lubricant loss analysis performed. These results must show that the lubricant survives in the unit for the specified life of the mechanisms with a margin of at least 10.

Consideration should be given to protection of molybdenum disulfide dry film lubricants from adverse affects due to exposure to atmospheric humidity.

## **2.8 CONTAMINATION**

A contamination analysis should be performed for all mechanisms to verify that lubricants, finishes, etc. will not contaminate HST, especially those mechanisms being inserted into the aft shroud.

## **2.9 GEAR ANALYSES**

All mechanisms utilizing gear trains should have an analysis performed to show positive margin for contact stress and fatigue based on program Safety Factor requirements.

## 2.10 TOLERANCE STUDY

Each mechanism shall have a tolerance study conducted. Close tolerance fits should use worst-case tolerance stack-ups at worst case bulk temperature and/or gradients.

## 2.11 TORQUE / FORCE MARGIN

All mechanisms should be analyzed to include all resistive torques / forces and show *at least* 200% with a goal of 300% torque / force margin over parasitic forces and *at least* 40% margin over inertial loads based on drive capability or applicable EVA activation force capability at worst case conditions. Resistive forces include all items that store or dissipate energy such as springs, dampers, and electrical cables in addition to those attributed to friction. Output Torque should never be less than 1.0 in-oz. Margin should be computed as follows:

$$\text{Margin (\%)} = \{ [T (\text{available}) / T (\text{resistive})] - 1 \} \times 100$$

$$T_a = (1.40 \times T_f) + (3.0 \times T_v)$$

Where:

$T_a$  = Available Torque or Force Minimum (formula shown is based on 200% margin)

$T_f$  =  $I\alpha$  (Fixed Torques or Forces not influenced by temperature or life)

$T_v$  = Parasitic Torques or Forces (Variable - Those influenced by temperature or life)

Deviations from this requirement are acceptable for EVA activated mechanism interfaces only where there is a redundant method of operation (EVA Override).

## 2.12 STABILITY MARGIN

Any mechanism using stepper motors should be designed such that there is 50% margin for rotor stability. At worst case operating environments, the motor shall be capable of synchronous operation with a rotor angular oscillation of 1.5 times (minimum) the corresponding oscillation at the minimum pulse width immediately following the powered state without missing steps or exhibiting any other anomalous behavior in both directions.

Stability Margin can be demonstrated using a reduced pulse width technique where the pulse width is shortened to the minimum value possible without missing steps or exhibiting any other anomalous behavior as verified by strip chart or other. The Stability Margin is calculated as the ratio of amplitude of oscillation immediately following pulse turn-off of the reduced to normal pulse width.

### **2.13 RELIABILITY / REDUNDANCY**

Component or part redundancy should be implemented where practicable, but should be used with caution. Redundancy that adds significant complexity and therefore reduces reliability should be avoided. A Failure Modes & Effects Analysis (FMEA) for each mechanism should be generated to show the areas of potential problems, redundancies, and effects on the mission.

### **2.14 LIFE**

If a mechanism is required to operate over the life of HST (i.e. motors, springs, flexures, etc.), an analysis should be conducted to show that the unit will meet all performance requirements over its required life with positive margin. A life test should be conducted at the worst case predicted environment to at least 2x the required operational life with a goal of showing 3x life.

## **3 CONCLUSION**

The requirements identified in Section 2 and Reference (a), Section 2.4.5, should be followed for all mechanisms on the HST project. Adherence to these will result in a robust mechanism deemed acceptable to the HST program. In addition, Reference (b), although no longer updated, is an excellent reference source and can be used as guideline for mechanism design and test unless its requirements conflict with those stated herein.

#### **4 REFERENCES**

- a) *General Environmental Verification Specification for STS & ELV Payloads, Subsystems and Components*, GEVS-SE.
- b) *Moving Mechanical Assemblies for Space Vehicles*, MIL-A-83577, February 1, 1988.
- c) JSC, *Mechanical Systems Safety*, MA2-00-057, September 28, 2000.